An Operational Technology for Assimilating Lagrangian Data Based on Dynamical Systems Techniques

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LONG-TERM GOAL

Much data in the ocean is Lagrangian in nature. Its full use in ocean prediction could advance significantly the Navy's ability both to predict ocean conditions and to assess the optimal strategies for deploying Lagrangian observational devices and their associated sensors. The development of a fully operational, integrated data assimilation scheme will afford such a naval predictive capacity in fixed ocean regions that can be comprehensively surveyed by Lagrangian measuring devices. The long-term objective of this project is the building of comprehensive and reliable data assimilation (DA) platform for incorporating Lagrangian data into ocean models. It will form the basis of an integrated prediction scheme for the ocean that can feed on both purely Lagrangian and mixed source data.

OBJECTIVES

This project aims to develop an operational technology for assimilating Lagrangian data. This new LaDA platform is expected to be particularly effective in ocean regions where coherent structures such as ocean eddies dominate the circulation. Focuses are put on: 1) extension of our Lagrangian data assimilation (LaDA) approach to develop a flexible platform, in which a variety of moving instruments that may not be viewed as Lagrangian in a conventional sense can be integrated; 2) design of observing systems to take full advantages of any moving instruments; 3) formulation of automated algorithms for optimal deployment strategies of the moving instruments to maximize the information content as observation and enhance predictive skill of the DA system; and 4) incorporation of dynamical systems theory to enhance predictive skill, in particular coherent structures and tracer fields associated with them.

By Lagrangian data, we mean both positions of moving instruments and also measurements taken by them. Autonomous vehicles (AUVs) that glide or maneuver in the ocean are new types of moving instruments that will be incorporated into our extended LaDA platform as a part of the control variables. AUVs have come to be a

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14. ABSTRACT
Much data in the ocean is Lagrangian in nature. Its full use in ocean prediction could advance significantly the Navy's ability both to predict ocean conditions and to assess the optimal strategies for deploying Lagrangian observational devices and their associated sensors. The development of a fully operational, integrated data assimilation scheme will afford such a naval predictive capacity in fixed ocean regions that can be comprehensively surveyed by Lagrangian measuring devices. The long-term objective of this project is the building of comprehensive and reliable data assimilation (DA) platform for incorporating Lagrangian data into ocean models. It will form the basis of an integrated prediction scheme for the ocean that can feed on both purely Lagrangian and mixed source data.

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stable and reliable mean to measure water properties. The platform will be ideal for designing and performing the autonomous ocean sampling network, adaptive observations, and optimal deployment plans of such moving instruments. The extension will also have a capability to handle high-dimensionality and nonlinearity of the operational ocean models.

A comprehensive LaDA platform will be built upon balanced integration of data assimilation techniques and dynamical systems concepts. Recent developments in the theory and use of dynamical systems concepts for Lagrangian analysis will add a new dimension to the LaDA platform. Incorporating the geometrical approach will offer a much needed template for observing system design for the LaDA platform. In return, accurate estimation and forecast of Eulerian flow field by assimilating such data will strengthen further the reliability of the observing system with moving instruments.

APPROACH

Our approach is to use the LaDA as a basis for the development of an operational technology that accommodates assimilation of data from a variety of measurements by any types of moving instruments including drifters, floats, and AUVs. Such a platform will be developed through a hierarchy of methods and models.

For the methods, the LaDA is implemented using the Extended Kalman filter (EKF), ensemble Kalman filter (EnKF), and particle filter (PF). In operational applications, the EnKF is the most promising technique currently. The EKF and PF are useful for providing the insight into the data assimilation problems and helping develop the basic concepts for sophisticated schemes of the observing system design in an operational environment.

Tests of our approach will be performed using the models, ranging form highly-idealized point-vortex systems, through intermediate shallow-water model in the basic-scale box configuration, to the realistic model configuration towards the operational application in Gulf of Mexico (GoM). The highly idealized models are used for the applications of the EKF and PF methods to gain and address fundamental issues associated with the LaDA. For operational applications, we will carefully address issues associated with the EnKF and the LaDA by incorporating the understanding gained from applications of the EKF and the PF methods.

Ideas from dynamical systems theory will be employed in every stage to provide a solid, mathematical template and foundation while casting conceptual simplicity on the complex platform.

WORK COMPLETED

Progress is being made in advancing LaDA towards operational use. This is being achieved using a hierarchical approach through a coordinated effort to 1) test and develop new schemes to strengthen the individual elements in the LaDA method and compare with other methods; and 2) design and test the optimal deployment strategies. Issues essential to the LaDA have been investigated further through a series of Observing System Simulation Experiments (OSSEs).

For practical reasons, the LaDA systems had been implemented using either the Extended Kalman filter (EKF) or the Ensemble Kalman filter (EnKF) in that past. Because both EKF and EnKF parameterize the background probability density by the error covariance, the LaDA system may experience occurrence of the filter divergence especially when the assimilation window is longer than the Lagrangian time scale of the Lagrangian instruments. To address this problem, several Particle Filter (PF) schemes that take the full background probability distribution into account have been carefully examined.

For the realistic applications of the LaDA towards the operational use, the three-layer shallow-water model with the Gulf of Mexico (GoM) configuration was refined further. To compare the effectiveness, a system for the assimilation of the velocity (Eulerian) data (EuDA) was also implemented in the GoM configuration. The EnKF methods were used in the GoM system.

For the estimation of the three-dimensional ocean evolving in time, the GoM system was used to quantify how effectively the surface (horizontal) information from the Lagrangian observation propagates vertically to the layer below.

The cost-effective deployment strategies were tested using the GoM system for the loop-current eddy tracking.

A scheme for the AUV assimilation was proposed based on the LaDA method. Initial tests were conducted using the GoM configuration.

Effectiveness of the LaDA method in comparison with the EuDA method was examined mathematically from the view of observability and control theory.

A variety of projects to advance and complement both the LaDA platform and dynamical systems concepts for ocean circulations have been pursued in a close collaboration with the group led by C.K.R.T. Jones at University of North Carolina at Chapel Hill.

A three-dimensional variational data assimilation scheme for the regional ocean modeling system (ROMS) has been advanced further. Improvement is being made for the treatment of dynamic balance and the model bias. This effort is lead by Yi Chao at Jet Propulsion Laboratory/California Institute of Technology in collaboration with the UCLA group.

RESULTS

Two types of deterministic BPF, cloud-expanding BPF and directed-doubling BPF, have been found effective in addressing the filter divergence (Figure 1). The backtracking capacity can be implemented in the EKF and EnKF.

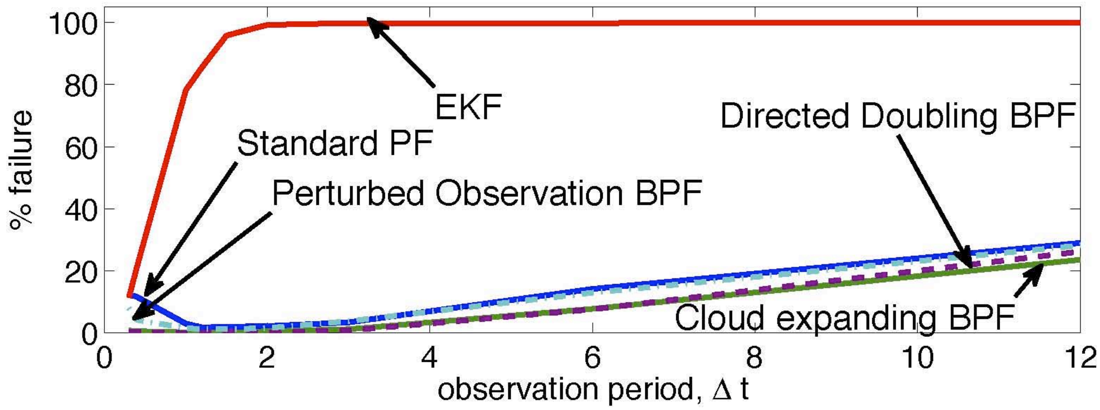

Figure 1. Failure rate (%) versus assimilation window (observation period) for an experiment comparing the different assimilation methods: EKF (red), standard PF (blue), Cloud-expending BPF(green), Directed-doubling BPF (brown dash), Perturbed observation BPF (green dash-dot).

Efficiency of the LaDA is addresed using the volume of influence (VoI) by individual observation. In the GoM system, the LaDA has much lagred expected VoI in comparison with the assimilation of the velocity data in all three layers (Table 1).

	E(VoI) by velocity	E(VoI) by LaDA
Layer 1	0.67	1.03
Layer 2	1.63	2.96
Layer 3	7.20	12.87

Table 1. Expected value of the VoI for the GoM system in the three layers ($10^{13}m^3$). The observation is taken in Layer 1. The VoI is larger for the deeper layers because of the larger depth.

Deployment strategy can be addressed using the eigenvalues and their condition numbers of the local observability gramians. This gives the theoretical support for the effectiveness of the LaDA methods.

IMPACT/APPLICATION

The LaDA-EnKF enables us to assimilate the drifter and float trajectory data into realistic ocean model efficiently.

The framework of the LaDA can be easily extened to assimilate the trajectory of the AUVs. This adds a new dimension to the benefit of AUVs as a part of the ocean observing system.

The flow-template approach, through the application of dynamical systems ideas, shows a promising potential to the effective design of the optimal and cost-effective deployment strategies for not only drifters but also AUVs.

RELATED PROJECTS

1– Los Alamos National Laboratory project on data assimilation studies for shock wave physics in collaboration with Jim Kao (Los Alamos National Laboratory).

PUBLICATIONS

Ide and C.K.R.T. Jones, 2008: Controlling the filter divergence in a Lagrangian data assimilation, to be submitted

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